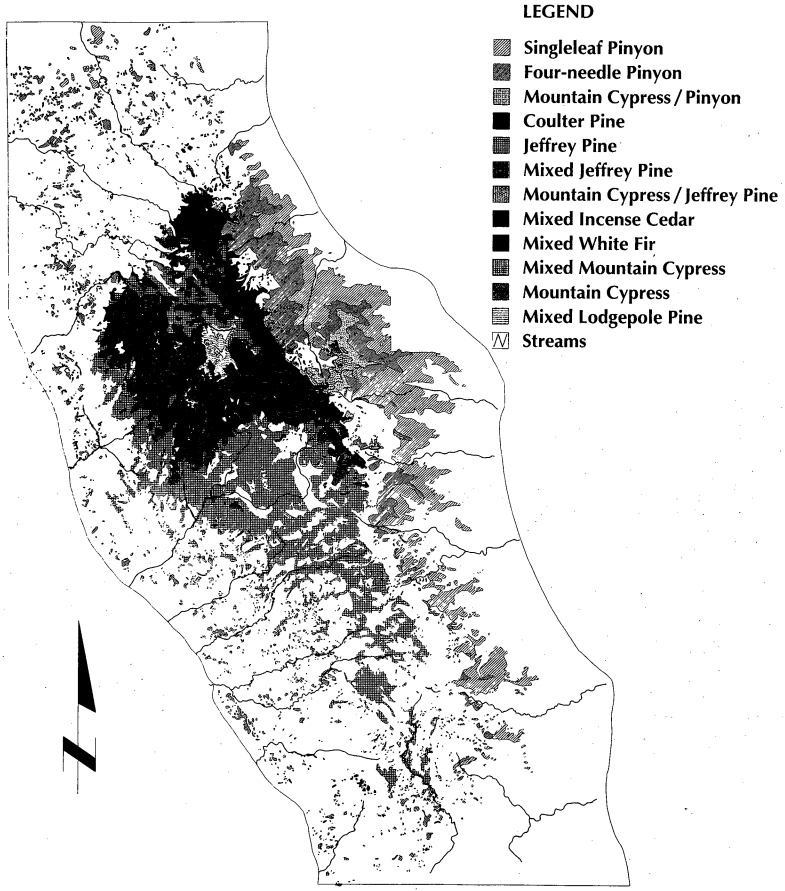
Santa Rosa meadow in the Sierra San Pedro Mártir of Baja California is surrounded by Jeffrey pines, with chaparral on the slopes. Photographs by Richard A. Minnich.

PROTECTING VEGETATION AND FIRE REGIMES IN THE SIERRA SAN PEDRO MÁRTIR OF BAJA CALIFORNIA

by Richard A. Minnich and Ernesto Franco-Vizcaino

THE HISTORICAL isolation of northern Baja California's Sierra San Pedro Mártir (SSPM) has served to protect its nearly pristine Mediterranean ecosystems. Summer-season livestock grazing, practiced since mission times, has given the Sierra a distinctive relationship between man and nature that is unique within the Californian floristic province. The Sierra's mixed-conifer forests and chaparral were insulated from conventional fire suppression management until the 1970s, and these fire-fighting practices are still largely ineffective. Fire suppression in California has encouraged stand thickening of forests and catastrophic brush fires, while uncontrolled fire in SSPM has maintained open, park-like forests and a fine-grained patch mosaic of chaparral. Consequently, societal differences in land management agendas have resulted in a natural experiment that has caused vegetation and fire regimes to diverge to the north and south of the U.S.-Mexico boundary. The Sierra's historical steady state is now at risk from increased commercial interests in the area, including livestock grazing, uncontrolled recreational use, logging concessions, and inappropriate fire management. This article examines how vegetation in SSPM can take on different states from that in California and attempts to show that the Sierra is the only extant scientific control for fire suppression policies. Indeed, the SSPM can be considered a unique laboratory for comparative and experimental studies from which to inform fire management policies in Mexico, the United States, and other regions with similar forests.

We first describe the distribution of vegetation on SSPM; this will have a familiar ring to those who know the floras of California's mountain ranges. An examination of how



Map of conifer forest in the Sierra San Pedro Mártir.

unmanaged fire shapes SSPM ecosystems follows. Finally, we discuss a proposal for establishing a biosphere reserve as a mechanism for conserving the Sierra's biological resources and cultural heritage by strengthening its traditional land use systems as a basis for a "let go" fire policy.

Physical Setting

The SSPM is a remote northwest-southeast trending fault-bound range sixty miles southeast of Ensenada, Baja California. The range consists of three terrain units. The eastern face is a dissected, precipitous fault escarpment with vertical relief of 3,300 to 8,200 feet above the Sonoran Desert. The crest consists of an extensive plateau with shallow, alluvial-filled basins and extensive meadows. The west face of SSPM is a steep, smooth fault escarpment with local relief of 900 to 1,600 feet. The plateau's altitude decreases in a step-wise fashion from 7,500 to 8,000 feet in the north (Vallecitos) to 6,500 to 7,000 feet in the center (La Grulla/La Encantada/Santa Rosa Meadows) to 5,900 to 6,300 feet in the south (Arroyo Santa Eulalia). To the north the Vallecitos surface descends to 3,300 feet in the El Huico basin. The high plateau is bounded on the east by a still higher ridge (8,500 to 9,600 feet), and on west by the Sierra Corona divide (8,500 feet).

From Vallecitos southward through La Grulla and La Encantada meadows, the Sierra consists of a massive granitic pluton that forms topographically irregular slopes. Granitic bodies that are resistant to weathering form spectacular surfaces of fractured bedrock at Cerro Venado Blanco and from Cerro Botella Azul westward to La Grulla. South of La Grulla and La Encantada are large exposures of metamorphic rocks that weather into topographically smooth slopes. Metamorphic units also outcrop in north-central Vallecitos near the National Astronomical Observatory, and along the northernmost ridge of the Sierra.

The SSPM lies at the southern margin of the North American mediterranean climatic zone of winter rains and summer drought. Long-term weather stations and bulk rain-gauge data indicate that mean annual precipitation, which is derived mostly from frontal cyclones off the Pacific, increases from ten inches at the western base of the range to twenty-seven inches at Sierra Corona. Precipitation amounts decrease to twenty-one inches in the central plateau, then decline rapidly down the eastern escarpment to six inches at the Sonoran Desert. The proportion of annual precipitation falling as snow, estimated from long-term storm snowlines, increases from fifteen percent at 5,600 feet to eighty percent at 8,500 feet.

Rainfall is scarce in summer except for local afternoon thunderstorms in July and August. The high altitude of the range results in a climate that is similar to stations in mixed-conifer forests of California, in spite of its southern latitude. Mean temperatures range from near 32°F in winter to 62°F in summer. Winter precipitation in SSPM is sixty to eighty percent of that at mesic stations in Southern California and the west slope of the Sierra Nevada. Precipitation amounts are comparable to leeward slope stations in Southern California and the eastside Sierra Nevada. Warm-season precipitation is slightly greater in SSPM than for California stations. However, lysimeter data at SSPM shows that summer rains do not generally moisten the soil at depths below twenty inches because of high evaporation rates. Hence, winter cyclones dominate the surface hydrology in the Sierra, as in California.

GIS of Vegetation and Fire History

The distribution of conifer forests, hardwood forests, and chaparral communities was mapped and entered into an arc/info geographic information system (GIS). Plant species were recognized on the basis of crown perimeter and apex configurations, vertical structure, shadows, and color as in Minnich (1987). We reconstructed the fire history by mapping landscape burn scars through site-specific matching of a series of ten aerial photograph coverages taken between 1942 and 1993. The procedure allows one to distinguish burn scars from the natural

heterogeneity of the vegetation. The time of fires was bracketed from the dates of aerial photos, then further estimated from the successional status of stands. Other coverages in the GIS include substrate, roads, trails, hydrology, and land ownership.

Vegetation Distribution

Ecosystems in SSPM show broad zonation with elevation and windward/leeward slope precipitation gradients associated with physiography, similar to that in California. Chaparral growing at lower elevations is replaced by extensive conifer forests on the high plateau and by pinyon woodlands on the eastern escarpment. The local patterning of communities is also modified by slope, aspect, and substrate.

The western flank is covered by chaparral dominated by chamise (*Adenostoma fasciculatum*) and red shank (*A. sparsifolium*). At the base of the western escarpment (3,900 to 4,200 feet), chamise forms partially open stands mixed with desert shrubs, including *Ephedra nevadensis, Simmondsia chinensis, Juniperus californica*, and *Yucca schidigera*. This is reminiscent of semi-arid, leeward slopes of coastal basins in Southern California, such as at Aguanga. *Ornithostaphylos oppositifolia, Malosma laurina*, and the drought-deciduous shrubs *Fraxinus trifoliolata* and *Aesculus parryi* may also be found at these altitudes. On mid-slopes (4,200 to 5,900 feet) chamise chaparral takes on a familiar uniform, carpet-like appearance with *Ceanothus greggii* var. *perplexans* an important subdominant. Few other shrubs are common, although *Rhus ovata* can be seen throughout the Sierra. Red shank chaparral, dominated by *Adenostoma sparsifolium*, tends to be extensive but patchy, with stands most widespread in the El Huico basin and in drainages west of La Grulla. Above 5,900 feet chamise and red shank chaparral are replaced by virtually monotypic stands of *Arctostaphylos peninsularis* (peninsula manzanita chaparral), which give a conspicuous blue cast to the Sierra from a distance. Dense stands of *A. peninsularis* may occur as high as 8,200 feet on the western escarpment.

Mixed chaparral, i.e., stands dominated by broad-leaf shrubs in *Quercus, Ceanothus*, and/or *Arctostaphylos*, does not occur in SSPM, although many species of this community find their southern limits in the range. *Arctostaphylos glauca* grows occasionally above 3,900 feet, and *Ceanothus leucodermis* is found near the chaparral/mixed-conifer forest ecotone. *Quercus dumosa* and *Heteromeles arbutifolia* are restricted to springs and arroyos. *Q. wislizenii* has been collected at a single locality, a cluster of tall shrubs at 6,200 feet along the road to the observatory. One of us (Minnich) has observed another colony at the same elevation on a north-facing slope near Sam's Corral. *Fremontodendron californicum* has been seen or collected only in few arroyos near the Mission San Pedro Martir and near Cerro "2040" in the southern SSPM. *Cercocarpus betuloides* has been seen on the plateau only in Arroyo Santa Eulalia. *Yucca whipplei* is remarkably scarce, and normally found on south-facing slopes near the base of the Sierra. The dominant succulent in chaparral is *Nolina palmeri*, which grows both in chaparral and in mixed-conifer forest up to 8,200 feet.

Few trees grow in the SSPM chaparral zone. *Populus fremontii* and *Salix* spp. form dense gallery forests along streams, especially along the tributaries of arroyos San Antonio, Valladares, Santa Cruz, and Rio San Rafael. Small stands occur in desert drainages, often in association with *Prosopis juliflora. Platanus racemosa* occurs occasionally in the southwest flank between Rancho San Antonio and San Pablo. *Populus trichocarpa* has been collected only at Arroyo la Grulla, two and a half miles southwest of the meadow and along Rio San Rafael. *Fraxinus velutina* has been collected only along desert arroyos in southern SSPM. Storms generated during the El Niño of 1993, which produced ten inches of rain during two days in January at Rancho Santa Cruz and perhaps two to three times as much on the plateau, resulted in widespread flooding, arroyo scouring, and denudation of riparian forests throughout the Sierra.

SSPM is southern limit of *Quercus agrifolia*, which occurs exclusively along arroyos, springs, and margins of meadows. Most stands are found on the western escarpment between Mike's Sky Ranch and Arroyo San Anto-

Spatial Extent of Vegetation Types of the Sierra San Pedro Mártir

Vegetation Type	Area (Acres)[1]
Conifer forest	
Jeffrey pine	48,324
Mixed conifer forest	37,999
White fir/sugar pine	8,399
Incense-cedar	1,368
Mountain cypress	1,959
Lodgepole pine	2,396
Coulter pine	385
Hardwood forest	
Canyon live oak	48,470
Pacific Emory oak	13,494
Quaking aspen	1,146
Shrub and herbaceous communities	
Chamise chaparral	133,375
Red shank chaparral	41,653
Peninsula manzanita chaparral	60,040
Timberland chaparral	52,365
Mountain meadow	6,395

[1] Calculated from the GIS.

nio at 3,900 to 6,200 feet. The tree occurs at higher altitudes in SSPM than anywhere else in its range except for the Santa Rosa Mountains in Southern California. A new colony was discovered on aerial photographs along Arroyo El Horno, seven kilometers southeast of known populations near Rancho San Antonio. *Q. agrifolia* was collected near the Pacific coast at the same latitude by Reid Moran on stream terraces of Arroyo Santo Domingo, near the Mission Santo Domingo ruins. It is absent from the El Huico basin with the exception of a single outlying population of twenty trees along a spring on the eastern escarpment.

The most common tree of the chaparral is *Pinus quadrifolia* (sixteen to fifty feet tall), which occurs in a fragmented patchwork of thousands of stands throughout the western escarpment. This tree also forms a continuous belt between 6,600 and 8,500 feet on the eastern escarpment before giving place to open forests of *P. monophylla* at lower altitudes. *P. monophylla* forests then continue downslope to about 3,900 feet, where they meet the microphyllous woodlands and creosote bush scrub of the Sonoran Desert. *P. quadrifolia* forests grow in chamise, red shank, or peninsula manzanita chaparral on the western escarpment and upper eastern escarpment, as well as in shrubby thickets of *Quercus chrysolepis* above 7,200 feet. Drier *P. monophylla* forests establish with open understory of desert chaparral dominated by *Quercus cornelius-mulleri, Q. peninsularis, Rhamnus crocea, Rhus ovata, Rhus trilobata*, and *Fremontodendron californicum*, as well as the leaf-succulents *Agave deserti* and *Nolina palmeri; Cercocarpus betuloides* occurs along arroyos. One of us (Minnich) collected *Rhus kearneyi*, a close relative of *Rhus ovata* and *R. integrifolia*, along Cañada la Providencia. It is one the few locations of this shrub outside its type locality in the Tinajas Altas of Sonora, Mexico. Desert scrub at the base of the escarpment includes microphyllous woodland dominated by *Prosopis juliflora, Cercidium floridum*, and *Olneya tesota*, creosote bush scrub species, and a few central desert succulents including the cardón (*Pachycereus pringlei*). Blue fan palm (*Brahea armata*) is abundant along moist desert arroyos and on cliff seeps in the southern SSPM as far north as Cañon El Cajón on the eastern escarpment and Arroyo San Pablo on the western escarpment. Desert scrub immediately east of SSPM has an unusually arboreal aspect for the Sonoran Desert as a result of frequent summer thundershowers moving over the area from the Sierra.

Tree species in Californian mixed-evergreen forest are rare or absent in SSPM. In California mixed-evergreen forest forms a transitional type between the chaparral and mixed-conifer forests. The mountains of Southern California, for example, have extensive forests of *Pinus coulteri* and *Pseudostuga macrocarpa* in association with *Quercus chrysolepis, Umbellularia californica*, and *Q. kelloggii*. In SSPM only *Q. chrysolepis* is widespread but as understory in mixed-conifer forest. A few stands descend into the chaparral belt on steep north-facing slopes and canyons to 5,900 feet. The tree is morphologically variable, as in California, but most stands consist of a small-leafed shrubby variant, although trees may grow as tall as eight-five feet along a few stream courses. The large-leaf form is occasionally seen on the west slope of Sierra Corona. Small groves of *Pinus coulteri* are found in clusters in the far northern and southern extremities of the Sierra. The northern population grows from 5,900 to 7,500 feet on north-facing metamorphic exposures, nearly four and a half miles north of Cerro Venado Blanco. The southern population grows on Cerro "2040," a summit of resistant granitic bedrock at 5,900 to 6,600 feet, with small groves extending five miles westward down an arroyo to 4,600 feet. Local landholders have long known about the tree. A cone can be seen at the Meling Ranch, and Felipe Meling collected mistletoe parasitizing *P. coulteri* at Cerro "2040" during the 1970s. Both Coulter pine forests grow in dense chaparral of *Arctostaphylos peninsularis, A. pringlei, A. pungens*, and *Quercus chrysolepis*. Tom Ledig states that there is more genetic variability in the rare *Pinus coulteri* populations of northern Baja California than all *P. coulteri* forests in California. He surmises that California populations represent a single race that spread northward into California after the Pleistocene.

Mixed Conifer Forest

In SSPM, mixed-conifer forest occurs above the chaparral or in habitats within chaparral where shrub cover is locally diminished or absent. The composition of tree species shifts with altitude and slope exposure. Forests between 4,200 and 6,300 feet are comprised of monotypic stands of *Pinus jeffreyi* growing in shrub-free basin floors, margins of meadows, and along arroyos. This pattern is similar to that of forests in the Sierra Juárez, as well as at Pine Valley (Laguna Mountains), Garner Valley (San Jacinto Mountains), and in the high basins around Gorman in Southern California. Above 6,300 feet Jeffrey pine forest expands from basin floors onto north-facing slopes, thinly veneered with shrub cover and/or *Quercus chrysolepis*. Jeffrey pine forest is most widespread along arroyo Santa Eulalia and around the three large meadows of La Grulla, La Encantada, and Santa Rosa. A few stands occur in canyon washes in the upper eastern escarpment north of the observatory, in basins or stream courses of the El Huico plateau, and on Cerro San Matías, an isolated peak of 7,200 feet nine miles north of the SSPM plateau. Important forest shrubs in *P. jeffreyi* forest include *Arctostaphylos pringlei, A. pungens, A. peninsularis, Quercus peninsularis*, and *Salvia pachyphylla. Artemisia tridentata* is surprisingly rare and seldom occurs above 5,900 feet. The largest stands of Great Basin sage occur in Arroyo Santa Eulalia, in the El Huico basin, and on lands cultivated 200 years ago at the Mis-

sion San Pedro Mártir. *Chrysothamnus nauseosus*, a common shrub in the western U.S., has not been reported in SSPM.

A botanical collection was taken by Reid Moran of an extraordinary population of Jeffrey pine, described by Wiggins (1944), along arroyo San Antonio at 2,300 feet. This population is remarkable not only for its low elevation, but also because the same colony may have been described by Junipero Serra two centuries before, who referred to "two big pine trees among the rest" at that site.

Above 7,200 feet *Pinus jeffreyi* forest is replaced by a zonal belt of mixed-conifer forest, similar to forests in California. South-facing slopes and valley floors are dominated by *P. jeffreyi*, with *Abies concolor* and *P. lambertiana* as important associates. White fir (*A. concolor*) dominates steep north-facing exposures on the plateau. *P. lambertiana* is most abundant on steep slopes and cliffs. White fir forest is most widespread in the mesic slopes of Sierra Corona and along the eastern divide between La Encantada and Cerro Venado Blanco. While most mixed-conifer forests occur on the plateau, stands locally descend north-facing slopes of the eastern and western escarpments to as low as 6,600 feet. A few populations of *P. lambertiana* also grow with Jeffrey pine on the shade of a few summits near La Grulla and La Encantada, the southern limit of that species. Reports by Wiggins (1944) of *A. concolor* near Santa Rosa have not been verified, and none have been reported at La Grulla or La Encantada.

Other conifers have only local distributions in SSPM. Incense-cedar (*Calocedrus decurrens*) grows along water courses and margins of meadows, chiefly on the west flank of the plateau. The southernmost colony (and southern limit of the species) occurs along Arroyo El Horno above Mission San Pedro Mártir. This tree also occurs in a few arroyos to the north and southwest of La Grulla. One colony grows below a waterfall along Arroyo El Potrero at 3,600 feet. The tree is common in most arroyos of the Sierra Corona, in the tributaries of Rio San Rafael, and on the west flank of Cerro Venado Blanco. It even becomes an important associate in white fir forests on the northern lip of the plateau. *C. decurrens* occurs occasionally on the west side of the Vallecitos basin, but is absent from the east side, including the eastern divide. The largest stand on the eastern escarpment is found along Cañada la Providencia between 4,600 and 6,600 feet. Smaller colonies occur north of the observatory along Cañon del Diablo and Cañon Copal.

The endemic *Cupressus montana* forms mixed stands with *Abies concolor* and *Pinus lambertiana* on the upper eastern escarpment, with the largest populations established on ledges and fractures on Picacho del Diablo. A few populations also occur along water courses on the plateau north and east of La Encantada. Reid Moran noted solitary trees along the stream between La Encantada and La Grulla and at Cerro La Vibora. Aerial photographs revealed new stands extending north ten miles along the escarpment from Picacho del Diablo to Cerro Venado Blanco. Young trees are found as low 4,600 feet along the floor of Cañada la Providencia.

Mixed conifer forest of *Abies concolor* (left), *Pinus lambertiana*, and *P. jeffreyi* on a north-facing slope southeast of Vallecitos.

Subalpine forests of *Pinus contorta* are common at the margins of meadows and along arroyos at Vallecitos. This tree also grows on northern exposures of Cerro Botella Azul, the highest summit of the plateau (1,000 feet), as well as on scattered bedrock surfaces along the eastern divide between that summit and the observatory. A few trees grow within the *Abies concolor-Cupressus montana* forest near the summit of Picacho del Diablo.

Only two hardwoods are common in mixed-conifer forest, *Quercus chrysolepis* and *Populus tremuloides. Q. chrysolepis* is widespread on steep, mostly north-facing slopes below 7,500 feet and south-facing slopes above that altitude. Compact colonies of *P. tremuloides* are common at Vallecitos and along the eastern rim as far north as Cerro Venado Blanco. Most colonies grow along arroyos and margins of meadows, although the tree extends locally onto north-facing slopes at CerroVenado Blanco and Cerro Botella Azul. An isolated colony occurs in the central Sierra along a canyon immediately west of Santa Rosa.

Mixed-conifer forests contain widespread open stands of timberland chaparral dominated by *Arctostaphylos patula. Ceanothus cordulatus* is common in recent burns. The closely related *C. palmeri* may be seen at the forest-chaparral ecotone on the west slope of Sierra Corona. Hybrids between these congeners and *C. leucodermis* may be seen along this ecotone. *Garrya grisea*, a SSPM endemic, grows on rocky slopes above 6,600 feet. A single population of *Cercocarpus ledifolius* has a foothold on a cliff just east of the observatory, its only known location in Mexico. This colony, which was apparently seen a century ago by Brandegee (1893), was recently observed by Robert Thorne. Little or no evergreen sclerophyllous shrub

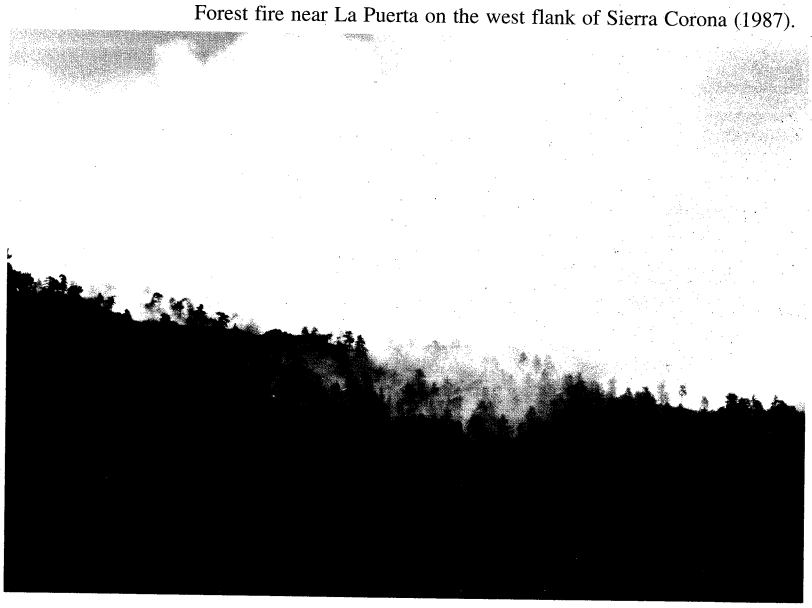
cover is found in forests at Vallecitos or on north-facing slopes of the eastern divide and Sierra Corona. Important subshrubs in mixed-conifer forest include *Symphoricarpos parishii* and *Holodiscus microphyllus*.

Herbaceous cover may be seen throughout SSPM forests, but it is usually less than ten percent as a result of summer drought. Dense cover is found only in mountain meadows dominated by *Juncus* and *Carex*, similar to California. Other common herbs include *Poa annua, Ranunculus cymbalaria, Epilobium adenocaulon, Astragalus gruinus, Oenothera californica, Berula erecta*, and *Cirsium foliosum*. Drier or overgrazed meadows are covered by herbaceous perennial species of *Achillea, Potentilla, Aster*, and the grass *Muhlenbergia*. The exotic *Bromus tectorum* may be seen along the meadow/forest fringe. This grass practically disappeared from SSPM during a bizarre winter in 1990-91. Apparently this grass flushed during sparse winter rains and above-normal temperatures in January and February, but was killed by one to two meters of snowfall during March.

The spatial pattern of the vegetation is strongly affected by substrate. In the chaparral, *Adenostoma sparsifolium* prefers granites, in a manner similar to that in the Sierra Juárez and in the Santa Rosa and San Jacinto Mountains of southern California. Likewise, *Quercus chrysolepis* and *Arctostaphylos patula* are most widespread in granites north of La Grulla and La Encantada. *Q. chrysolepis* understory shifts abruptly to *Q. peninsularis* mixed with *Arctostaphylos pringlei* and *A. pungens* on metamorphic units to the south. At Vallecitos *Q. peninsularis* grows exclusively on metamorphic slopes west of the observatory. *Populus tremuloides* is almost entirely restricted to granitic substrate. Among conifers, *Pinus jeffreyi* forests avoid chaparral-covered slopes in metamorphic units, but thin stands grow on slopes having granitic substrate. Similarly, *Abies concolor* and *Pinus lambertiana* are more abundant in granites than on metamorphic zones at comparable altitudes. For example, both trees dominate forests on the rugged Cerro Venado Blanco granites, even on south-facing slopes, while *A. concolor* is scarce, and *P. lambertiana* is absent in metamorphics just to the south. *Cupressus montana* occurs exclusively in granitic zones, avoiding metamorphic substrate between the observatory and Cerro Venado Blanco.

In general, granitic zones support more mesic species than metamorphic units. The coarse, sandy soils that develop in the granitic zones have higher rates of water infiltration, and hold water less tightly, than the finer loamy soils that develop on metamorphic rocks. Moreover, the impermeable granite channels runoff towards the inter-rock zones and prevents deep percolation from overlying soil.

Forest fire near La Puerta on the west flank of Sierra Corona (1987).



Wildland Fire

Fire is an important influence on species composition, as well as on the structure and function of both chaparral and forests in SSPM. The mediterranean climate results in temperature and moisture conditions unfavorable for decomposition but favorable for fuel build-up and high fire hazard. The frequency of fire (number of events per unit time) is high, but even without fire control fire recurrence intervals are long in the Sierra, averaging about fifty years for both chaparral and mixed-conifer forest. Long fire return intervals are associated with a gradual increase in successional fire hazard related to low production rates of fine fuels and gradual build-up of canopy, combined with high moisture in the vegetation. Both chaparral and conifer forests are comprised of evergreen sclerophyllous species, which have good stomatal control to reduce transpiration under high evaporative demand, but this results in low photosynthetic rates.

Only a small portion of fixed photosynthate is allocated into "flash fuels" (small stems and foliage), with the remainder invested into fire-resistant wood (large stems and tree boles). Even conifer needles accumulating on the ground have a limited capacity for supporting flash fires because packing of the litter bed reduces the exposure of needles to oxygen.

Without fire control, these trends bring about a predictable spatial pattern in fire occurrence. During 1925-91 fires burned a total of 352,200 acres, mostly in chaparral and conifer forest on the west slope and plateau. While the number of fires in SSPM is high (865 since 1925), the size of fires responsible for most burn acreages (sixty-one percent) is small (125 to 4,000 acres), or about ten times smaller than for California under fire control. The inverse relationship between fire frequency and size is produced by uniform burning rates related to a time-dependence in fire hazard. Most large fires in both chaparral and conifer

forest establish in old-growth stands (greater than fifty years), but these burns form narrow overlap zones with recent burns that lack sufficient fuel to sustain flame lines. In other words, mosaics of fire-created patches are shaped by patch structure caused by previous fire history. Hence, the pattern of patch turnover is spatially non-random and loosely self-organizing, such that we can predict future fires from the patch mosaic, in a manner similar to that in the Sierra Juárez and Southern California.

Non-random fire occurrence can also be seen in the gradient in fire return intervals across SSPM. These increase from forty to fifty years in the chaparral and conifer forests on the mesic west slope to eighty years in mountain cypress forests on the eastern summits. In the pinyon forests on the xeric eastern escarpment, fire return intervals may be as long as a few centuries. This trend suggests that forest productivity is proportional to mean annual precipitation, indicating that the more mesic western plateau forests have faster fuel build-up than the drier eastern forests.

The high frequency of fires is related to summer thunderstorms which coincide with summer drought. Indeed, trees damaged by lightning can be seen throughout the Sierra. However, most lightning discharges fail to establish fires since flux rates of cloud-to-ground lightning are forty-six times greater than burns. High rates of fire failure are thus due to the overabundance of discharges. Given present lightning discharge rates, a median size patch in the mosaic (600 acres) sustains a discharge every three years, or about twenty times per fire interval. Clearly, most lightning strikes will hit stands that have insufficient fuels to sustain large burns. Evidence that supports this assertion was seen in aerial photographs taken in July 1991 in which were recorded 212 spot fires, likely from thunderstorms that occurred earlier in the month. Nearly all these spot fires were less than two and a half acres in size, and none had been suppressed.

How fire denudes vegetation in SSPM depends on its structure. Chaparral is characterized by continuous shrub cover and efficient burns remove most above-ground canopy. The fragmentation of the stand mosaic by numerous fires precludes large burns. After fire, resprouting shrubs, joined by seedlings germinating from seed cached in the soil, form closed canopies after five to twenty years, and stand height reaches maturity after thirty years. Short fire recurrences are discouraged because little fuel remains after fires, and flames seldom pass through young, open stands. As stands age, they gradually become more flammable due to such factors as dead fuel accumulation, increasing fuel continuity with shrub closure, and the expanding foliage hastening the onset of seasonal drought stress. Chronosequences of post-fire succession along the U.S.-Mexico border show that chaparral appears to be stable both under frequent small fires, as seen in SSPM, and under infrequent large ones on the U.S. side. Shrubs either resprout or recruit from dispersed seed caches, thus permitting efficient stand establishment under variable fire sizes and intervals.

Forests of both *Pinus quadrifolia* and *P. monophylla* are killed by fires because they grow among abundant chaparral fuels and their canopies are contiguous with the shrub layer. No studies have documented the post-fire succession of *P. quadrifolia*. Repeat aerial photographs suggest that the tree aggressively colonizes burns. Seed dispersal over long distances is apparently due to caching by birds, because both cones and seeds are destroyed by fire. This is supported by a trend for stands to be mixed-aged as a result of continuous recruitment, as is typical of white pines. Fragmented stands on the west slope correspond with old-growth chaparral. Younger stands no doubt have saplings, but these cannot be seen on aerial photographs. The greater continuity of forests on the upper eastern escarpment appears to reflect longer fire intervals and succession times there.

Similarly, no studies have been undertaken on the fire ecology of *Pinus monophylla* forest in Baja California. In SSPM most burns appear to be crown fires because shrub cover in this ecosystem is too open to sustain flame lines over large areas. Few stands have burned since 1925, and fire return intervals are estimated at more than 500 years. Post-fire succession may be similar to that in Southern California. Denuded forests are colonized by a dense shrub layer of great basin sage scrub or desert chaparral. Establishment of *P. monophylla* is delayed twenty to thirty years during freeze-thaw cycles, and early recruits appear to take root within the canopies of shrubs that act as nurse plants. (Most stems are only half an inch away from shrub root axes.) The gradual development of pinyon canopy after about seventy-five years eventually ameliorates freeze-thaw processes, setting off a chain reaction of spatially random recruitment. Canopy closure develops after 100 to 150 years, with a corresponding decline of the shrub layer.

The stand characteristics of *Pinus coulteri* forests in SSPM appear to be a manifestation of canopy fire regimes. Few fully mature stands have burned since the earliest aerial photograph coverage in 1942. Trees have even stature and are presumably even-aged. Stands that have burned since 1942 were almost entirely fire-killed as a result of the small stature of the trees and the occurrence of stands in dense chaparral. Aerial photographs show even-aged *Pinus coulteri* stems emerging through brush within twenty years after fire. The trees appear to recruit during first growing season from seed dispersed from partially serotinous cones. Local populations survived burns on fire-resistant rocky hillsides. These sites appear to provide a secure seed source that may become critical when fires are followed by drought severe enough to cause recruitment failure.

Mixed-conifer forests are open and park-like, with stand densities of fifty to 150 stems per hectare; this is likely the result of recurrent intense surface fires about every fifty years. Although the openness of forests has been attributed to porous soils and dry climate, there is evidence that

Chaparral fire mosaic near Santo Tomás meadow in the southern Sierra San Pedro Mártir.

stands would become denser if fire were excluded, in a manner similar to that of forests in California. Sapling densities are two to four times that of overstory trees (250 to 1,500 per acre), and succession chronosequences reveal an increase of thirty-seven pole-size stems per acre after fifty years. Local forests that have not burned for more than seventy years support tree densities as high as 1,000 stems per acre, similar to forests that experienced stand thickening in Southern California and in the Sierra Nevada. Ground fires destroy both saplings and most pole-size trees as large as ten to fifteen meters tall, leaving the canopy layer intact. There is little evidence that SSPM forests are undergoing stand thickening at the landscape scale, even with fifty-year fire intervals, because the growth of new stems is countered by high fire mortality rates. Most SSPM forests continue to be dominated by old-growth pines; by contrast, in California forests show an age-specific trend away from dominance by mature *Pinus ponderosa* or *P. jeffreyi* and toward dominance by juvenile, pole-size classes of *Abies concolor* and *Calocedrus decurrens*.

Fires appear to play a major role in shaping forest distributions through a changing balance between disturbance-generated stand destruction and post-fire regrowth along environmental gradients caused by climate and fire/terrain interactions. For example, *Pinus quadrifolia*, which has a higher reproductive capacity than *P. monophylla*, is able to persist under recurrent fire on the western escarpment, while *P. monophylla* survives in environments with low fire hazard on the arid eastern escarpment. Neither pinyon would fare well beneath mixed-conifer forest because of selective elimination by understory fires.

Pinus coulteri, which has an obligate seeding strategy related to its partial cone serotiny, benefits from stand-replacement fires encouraged by dense chaparral and steep slopes. Intense burns result in efficient seedling establishment by enriching soils and reducing competition from shrubs. Intense burns would also give *P. coulteri* selective advantage over mixed-conifer forest tree species that have inadequate reproductive capacity to persist under short-period canopy fires. The primary adaptation of mixed-conifer forest tree species is their ability to survive understory fires because of their thick bark and tall stature. These stands grow in areas with low chaparral biomass—either above the chaparral belt or in flat terrain within the chaparral belt.

Sierra San Pedro Mártir Biosphere Reserve

The SSPM is currently at risk from inappropriate fire management, as well as increased commercial interests in the area, chiefly logging concessions. Until the 1970s the isolation of the Sierra insulated the region from conventional fire management practices, and the park-like forests of SSPM present a living reminder of "natural" nineteenth-century woodland environments in California and the southwestern U.S. Indeed, SSPM is a rare natural laboratory for comparative and experimental studies with which to inform management policies in Mexico and the U.S. because the maintenance of ecosystems or restoration of altered ecosystems requires knowledge of the past. In addition to its well managed (through no management) fire ecology, the Sierra hosts extraordinary biological diversity and traditional examples of land uses. The area is home to Douglas squirrel (*Sciurus douglasii*), a close relative of the Kaibab squirrel of northern Arizona. One to two thousand bighorn sheep live on the eastern escarpment, and an endemic fresh-water trout (*Oncorhynchus mykiss nelsonii*) dwells in two western streams. The giant California condor (*Gymnogyps californianus*) ranged over the mountain plateaus as late as 1940. The northern SSPM is inhabited by the Kiliwa *rancheria*, one of the last hunter-gatherer Indian cultures remaining on the Pacific Coast between Canada and the tip of Baja California, and the Mission San Pedro Mártir archeological site remains unpillaged by looters. Isolation has also preserved a traditional summer-season livestock grazing system that dates back to Dominican mission times of the late eighteenth century.

However, rapid population growth in the region, coupled with increased interest in the Sierra's natural resources, presents a challenge to sustainable use of the region. While traditional cattle grazing and selective logging in the past have not led to severe degradation of the environment, policies for future use should be established before conflicts over land and resources develop. The Sierra is an ideal site for the establishment of a biosphere reserve under UNESCO'S Man and the Biosphere (MAB) program and Mexico's national committee for this program (MAB-Mexico). The biosphere reserve program encourages the integration of traditional human activities with conservation practices through interdisciplinary research programs that aim to improve the management of protected areas.

Initial studies carried out by a bi-national team of researchers have examined fire ecology, surface hydrology, soil fertility, and grazing impacts on meadow vegetation, as well as archaeology and cultural history. These have been complemented by studies of the ecology of the forests and of the San Pedro Mártir trout carried out by other international teams. As a biosphere reserve, a scientific advisory committee would be established to assess the sustainability of present and proposed land uses and to provide scientific information to establish a management plan. The participation of local landholders would be a prerequisite in making decisions about allowable land use. A biosphere reserve may also bring new economic opportunities, such as ecotourism, which are compatible with conservation goals. The importance of the biosphere reserve concept is that it would bring together a community of landholders, scientists, and conservationists who would work together to maintain the benefits of the Sierra's resources, while keeping them in the hands of the local people. As part of this plan, one goal would be to introduce a "let go" fire management plan that maintains the uncontrolled fire regime that has existed in the Sierra since prehistory.

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See page 12 for author addresses.